The Use Of Technology In Preparing Subway Systems For Chemical/Biological Terrorism

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ABSTRACT

Recent events have raised concern among public transit agencies regarding the potential for chemical or biological terrorism. In particular, the sarin attack in the Tokyo subway in 1995 revealed that a significant number of casualties could result from even a small release of a chemical agent, due to the high density of people in the subway and the spread of agent by the movement of trains. In an attack, people are likely to be impacted in stations, in trains, and above the ground. The Department of Energy PROTECTS Program (Program for Response Options and Technology Enhancements for Chemical/Biological Terrorism in Subways) is aimed at developing and applying technologies that can save lives in a chemical or biological incident in a subway. The program is pursuing a systems approach to the problem, including consideration of detection, model simulation for transport and fate, communications, decision support systems, decontamination, training tools, and exercise and response planning.

This paper describes technologies that can be put into place in a subway system in an attempt to save thousands of lives in an incident. Detection technologies are relatively immature, and will therefore require testing and possibly further development work before they can drive automated system responses. System reliability may be enhanced through the use of support systems such as closed-circuit TV and redundancy of technologies. Such system concepts will be evaluated and demonstrated in a subway environment in the next 2-3 years by the Department of Energy laboratories.

Current incident response recommendations involve "containing" the chemical or biological agent rather than "venting" it. A release in a subway system is carried below ground by train movement, any operating fans, and the movement of people. The time to action after an agent is released is the key to saving lives and determines which technologies are best suited for mitigating the impacts of an agent release. The development of more specific recommendations awaits improved modeling techniques, and the exercise of such models for a wide range of attack scenarios.

INTRODUCTION

The network of a subway system, with its tunnels, moving trains and ventilation shafts, can distribute a chemical or biological (C/B) agent throughout many stations and tunnels below ground, and up through ventilation shafts and station egresses above ground to an entire city. In fact, the release of a biological agent in a subway could lead to the exposure of more than 100,000 people, counting those in the subway and those in the city above. If no rapid and inexpensive biological agent detection capability is available, as may remain the case for the next few years, it could be 48 hours or longer before anyone would be aware that a biological incident had occurred. Hospitals would likely be the first to see the evidence of an attack. Figure 1 illustrates a similar problem with photographs taken during the Tokyo subway sarin incident, in which 12 people died and 5,500 people sought medical attention.

The terrorist threat to U.S. subway systems comes both from rogue nations that can pass weapons of mass destruction to terrorists for use inside the United States, and from homegrown terrorists who have their own political agendas. Although U.S. intelligence sources can track and limit the activities of known terrorist groups; they are unlikely to be aware of all potential terrorist activities in the United States. Intelligence, law enforcement, and emergency management communities face a unique challenge in addressing the terrorist threat considering the ease in accessing C/B agent "recipes" on the Internet and the relative ease in constructing some weaponized agents.

This paper briefly describes PROTECTS (Program for Response Options and Technology Enhancements for Chemical/ Biological Terrorism in Subways), the U.S. Department of Energy (DOE) initiative that represents an integrated approach toward dealing with such incidents. PROTECTS covers preplanning as well as emergency response during an event in a subway system. The current

PROTECTS
(Program for Response Options and Technology Enhancements for Chemical/Biological Terrorism in Subways)

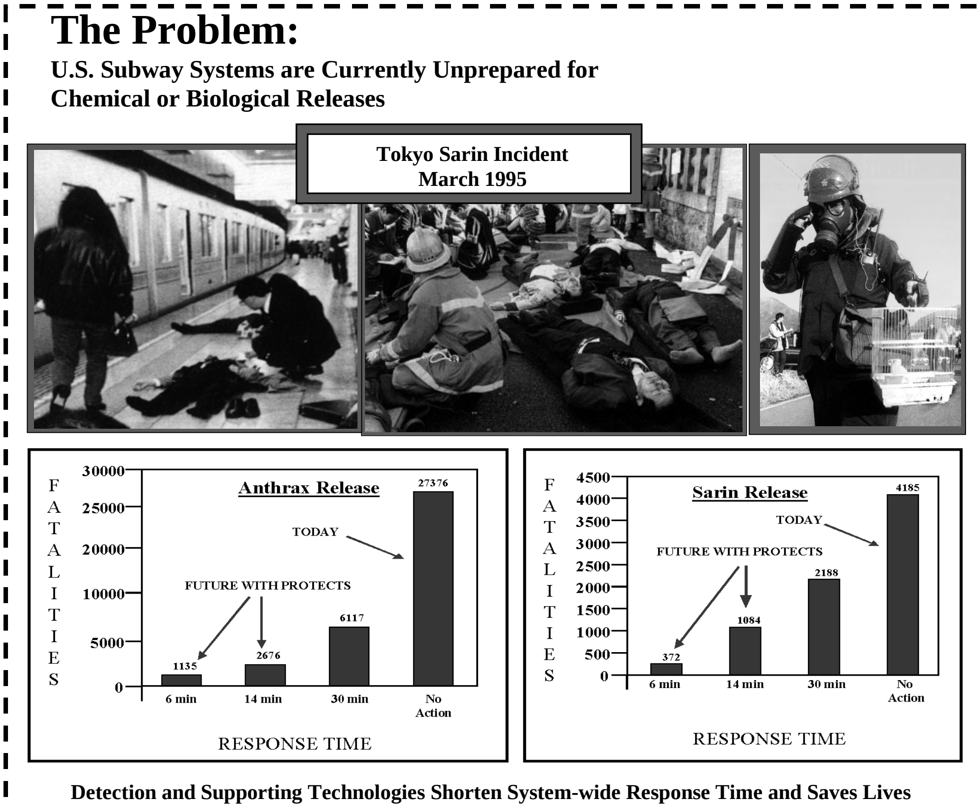

Figure 1. Problem of a Chemical Attack on a Subway System

PROTECTS team is led by Argonne National Laboratory and Sandia National Laboratories for DOE.

PROTECTS is developing new technologies for emergency planning before incidents occur and advanced emergency management tools for emergency response. PROTECTS will illustrate the use of these technologies in a demonstration program at a U.S. subway system in approximately 2-3 years.

UNDERSTANDING THE PROBLEM

A terrorist can attack a subway system in three general ways with C/B weapons:

1. release in a station,
2. release in a train car, and
3. release in a tunnel, perhaps from a grating at street level down though a ventilation shaft.

Spreading of the C/B plume is driven by moving trains that disperse the agent throughout stations and into the tunnels to subsequent stations. In any of these releases, time is lost before system-wide action can take place, and during that time the agent can spread and impact new victims. Response time includes the time before the incident is reported, the time when decision makers at the Operations Control Center (OCC) determine what to do, and the time when OCC implements its emergency management decision. The addition of detectors in the subway system and use of closed-circuit TV (CCTV) with decision analysis software in the OCC could significantly reduce the length of this lost time in the future.

There are many possible terrorist attack scenarios. A terrorist may release either chemical or biological agents. Chemical agents include nerve, blood, choking, blister, and incapacitating agents. Biological agents are even more diverse. C/B agents may be released by evaporation, with an aerosolizer, or with an explosive, and they may be released from a single location or multiple locations.

Two chemical attacks that occurred help illustrate likely attack scenarios. In March 1995, the famous chemical attack by Aum Shinrikyo on the Tokyo subway involved the evaporative release of sarin gas in multiple trains converging on a single target station. In May 1995, an attempted cyanide gas attack was narrowly averted by subway guards. A small fire was used to create and disperse hydrogen cyanide gas from a restroom that ventilated to a station platform [1]. These two attacks demonstrate the diversity of possible attack scenarios, since they involve different gases, release mechanisms, release locations, and single versus multiple releases.

To develop a holistic solution to the problem, a number of issues need to be evaluated, as shown in Figure 2. They include assessment of vulnerabilities, detection, crisis management, modeling and simulation to determine response strategies, control options, and after-event decontamination. These issues are categorized into four main thrust areas for PROTECTS, also depicted in Figure 2.

To date, much of the work on PROTECTS has been in the areas of effects modeling and engineered responses. Model simulations made as of March 1999 with an ANL-developed C/B post-processor to the well-known Subway Environment Simulation (SES) Model have been supported by some GASFLOW 3-D Computational Fluid Dynamics (CFD) Model predictions. Those results have indicated that the following factors are important:

Piston Effect

After an agent release has started, the piston effect caused by the movement of trains spreads an agent into tunnels and neighboring stations and up ventilation or fan shafts to street level.

Train Car Effect

The operating heating, ventilating, and air conditioning (HVAC) system in a train car can entrain C/B agent into that train car from outside leading to exposure of the patrons riding the train. Continued operation of the HVAC system can then remove the agent over time, moving it into the tunnels and stations as the train car operates. Trains opening their doors at a station and people exiting and entering the train cars lead to additional exchanges of the agent with subway station air.

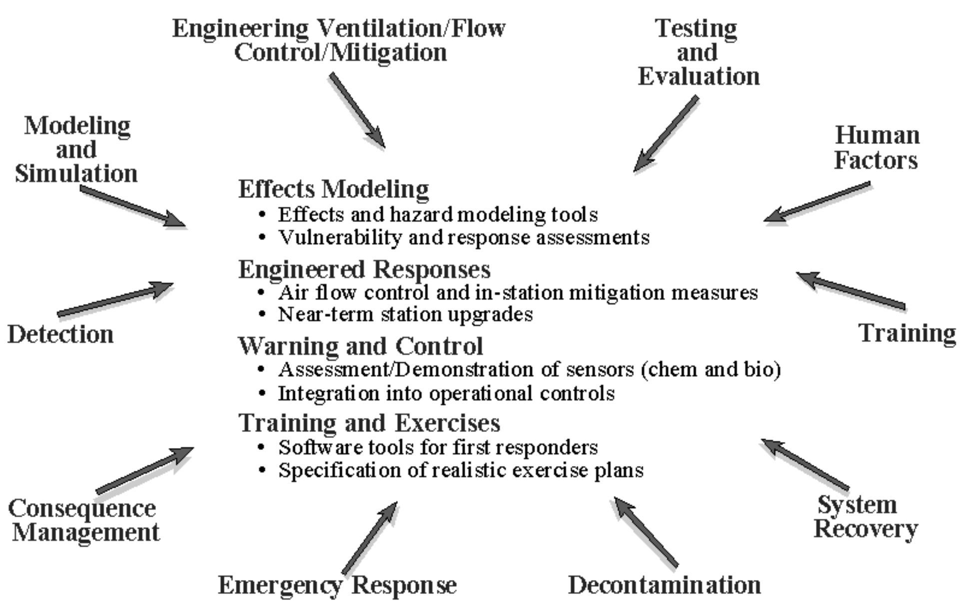

Figure 2. Major Thrust Areas for PROTECTS

Effect of Stopping Trains

Shutting trains down does not immediately stop the spread of an agent since the inertia of the air generated by train movement does not halt immediately when trains are stopped but rather continues until it is dissipated by friction. This additional air movement can spread 300 feet or more beyond the stopping point of the trains. The additional time lag and additional distance for dispersion must be considered in implementing emergency response actions and recognizing which patrons are at risk. Also, it is not likley that subway air motion stops completely when trains halt due to wind blowing into stations, elevation differences, and temperature gradients. More research is needed here.

Venting Versus Containing

Generally, turning fans on to ventilate the agent to the street and dilute agent concentrations is not a good idea based on current simulation modeling results. Some operational staff at transit authorities have recommended that the emergency ventilation fans (used for fire and smoke) be turned on to rapidly vacate the subway of the agent, thereby allowing the system to be decontaminated and recovered to revenue service as quickly as possible. In fact, venting may be useful for less lethal agents; lives may be saved when fresh air and oxygen are added to the cloud. However, venting is not wise for nerve agents; even very low concentrations may injure or kill many more people at street level than in the subway. Additional model simulations will determine if the above findings are true in all circumstances.

Venting of a biological agent could cause even more disastrous consequences. Biological agent plumes emitted from stations and tunnels through vent shafts to street level may travel 7 to 10 kilometers or more above ground with deadly impact, depending on the agent, amount released, and train movement. Agents emitted from subway vent shafts and station egresses can also enter nearby buildings and their HVAC systems, and impact people in those buildings as well. The choice to vent or contain a C/B release should be based on site-specific computer model runs. Thus, without knowing the identity of an agent, a default policy of containing the release and preventing its spread appears to be better in terms of lives saved than a policy of venting the release to street level.

It may be one year or more before chemical sensors are tested and validated for subway use and installed in subway systems. A 3 to 5 year period is likely for chemical sensors that can detect many types of agents and for biological agent detectors. Until such products are available and proven, a general policy of containment appears to be better than a policy of ventilation. As noted above, running additional computer simulations to compare such options should be done to determine how widely this recommendation is likely to apply.

Single Versus Multi-Track Tunnels

Trains can move 50 to 60 miles per hour in a tunnel; however, agent-filled air moves, at most, only about 30 miles per hour. A series of trains can pass through an agent cloud as it travels in the direction of train movement in a single-track tunnel. Net air movement is slower in double-track tunnels than in single-track tunnels because the air shifts in direction as trains move in opposite directions. Air movement in four-track tunnels reveals a very small piston effect; air is mainly stirred up each time a train passes. This small piston effect is due to the fact that a train's cross-section may fill only about 20% of the tunnel's cross-section. Each track section needs to be evaluated separately to be certain of the optimal response strategy for that section.

Response Time Is Critical

Reducing the amount of time it takes to implement a system-wide response is critical to saving lives. The faster the emergency response, the more lives can be saved. Figure 1 shows the results of computer modeling that estimates the number of lives that could be saved as a result of a system-wide action, in this case stopping trains and shutting all fans for both a chemical and biological agent. For the biological release, no action refers to the current situation of no detection, and the future situation refers to detection capability leading to responses in 30, 15, and 6 minutes. For the chemical agent release, no action refers to the continued operation of trains (benchmark case) as compared to stopping trains in 30, 15, and 6 minutes.

THE PROTECTS TECHNOLOGY SOLUTION

Detection may provide a key technology solution in preparing subway systems for C/B attacks. The best use of detection technologies will vary among subway systems and will likely change as new detection technologies become available. A typical example of a detection system is shown in Figure 3. Chemical or biological detectors report to the OCC and to the station manager in the kiosk. When an alarm sounds at the OCC, personnel can confirm for example, that an incident is occurring, and that it is not

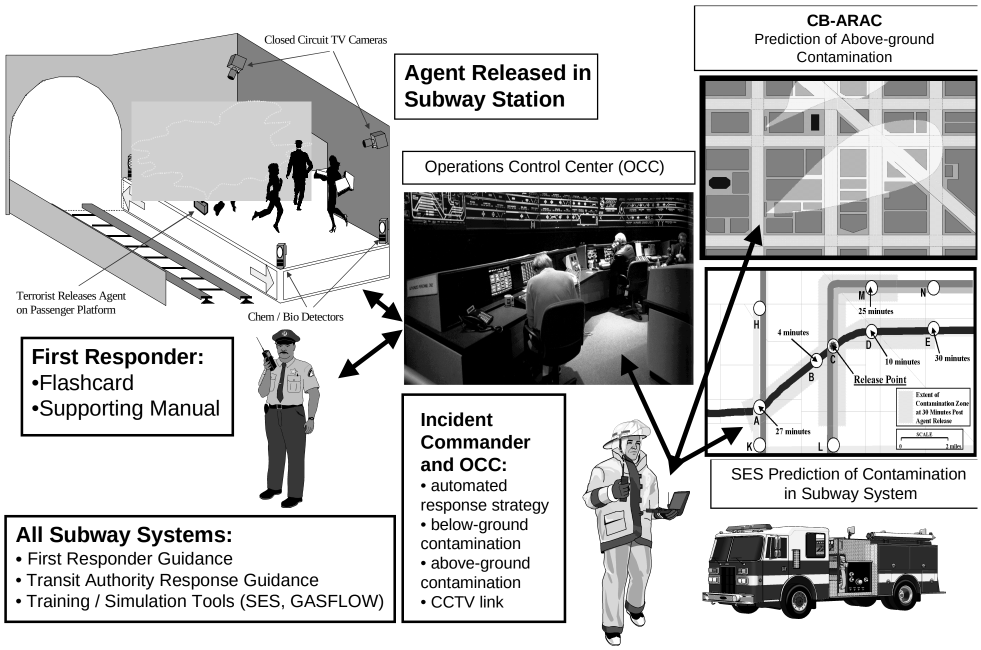

Figure 3. PROTECTS Plan for Emergency Response During a Chemical Agent Attack

a false alarm, by inspecting closed-circuit TV images of the affected area. Once the incident is confirmed, automated response strategies, developed through pre-planning, based upon modeling are implemented. On the basis of which detectors report agent concentrations and which agent is identified, an estimate of the spread of the plume in the system as well as emissions amd plume spread to the street will be performed and made available to OCC personnel.

There are other supporting technologies to be evaluated that could be used to save lives in such an incident. Their cost-effective use in terms of lives saved as compared to cost is yet to be evaluated. Among the technologies are:

a. an inflatable barrier that can block the spread of agent to the remainder of the subway system;
b. station mitigation methods such as water curtains, air curtains, and water or foam sprays;
c. first responder and incident commander support tools; and
d. training and exercises.

Training materials could be in the form of virtual reality simulation tools, including the visualization of model predictions during a hypothetical incident. Most subway systems have the infrastructure to permit the implementation of this plan for stations in terms of their communication systems, supporting software, and OCC hardware capabilities.

First responders might uncover an incident in locations not covered by detectors. First responders such as transit police would not likely have personal protection equipment or portable detectors but they would probably become the first line of reporting to the OCC. The plan is that they would be given a flashcard to carry with them, reminding them of actions to take. The flashcards would be backed up by a more detailed manual and supported through training and exercises. Firemen and hazmat (hazardous material) teams responding to the incident would be armed with a hand-held device that could receive the same information as that available in the OCC. The information would include prediction of the hazard zone below ground, prediction of the hazard zone above ground, and CCTV images of the station under attack broadcast from that station's own CCTV hookup.

The following sections further explore key components of PROTECTS in the areas of C/B warning, decision support and response.

C/B Warning and Response

In the event of a C/B terrorist attack on a subway, rapid detection and response can play a critical role in saving lives and reducing casualties. As discussed above, the longer it takes to detect and respond to an attack, the more a released C/B agent will spread through the system, harming more people and exacerbating decontamination. As trains move through the system, in the absence of platform edge doors, air pushed by the trains spreads a released agent throughout a station and beyond to neighboring stations. A detection and warning system, together with a well-orchestrated response strategy, can significantly reduce the consequences of an attack. As discussed earlier, our preliminary modeling results indicate that overall casualties are reduced by stopping train movement within minutes of an attack thereby vastly reducing the rate of agent spread.

An effective warning and response system to handle such attacks must incorporate two important components. First, a detection system must be developed that employs available technologies and methodologies to rapidly detect a C/B attack on the subway system. Second, a response plan must be developed that will allow the subway employees at the stations, on the trains, and at the OCC to minimize the number of casualties in an attack without causing risk to themselves in the process. The response plan should include the use of available mitigating technologies to minimize the impacts of an attack.

Detection

A detection system that monitors for signs of a C/B attack must include technologies and procedures designed to detect and confirm that an attack is taking place within a short time of when the agent was released and with a low or no false alarm rate. We are currently evaluating the utility of sensing, artificial intelligence, and video technologies for such a detection system. Thus, detection does not include only chemical and biological agent sensors but also incorporates other technologies and procedures that may help to rapidly identify and confirm an attack. For example, artificial intelligence algorithms may be developed that are capable of recognizing patterns of sound or motion in a station that are characteristic of a panic situation [2,3]. Such algorithms could cue the OCC that an attack is suspected, shaving precious minutes off the emergency response time.

More classical detection methodologies would employ chemical sensors that alarm in the presence of chemical agents. We are investigating the use of sensors, such as IMS, SAW, and FTIR sensors, for this purpose. The dream detector for detection and warning would be small, cheap, sensitive (sensing small concentrations), selective (distinguishing between agents), reliable, and autonomous. It would have a fast response time and a low false alarm rate. It would detect many types of agents, require little maintenance, and use no consumables. Although the sensors available today are not yet capable of meeting all of these requirements, detection of some chemicals may be possible with small, autonomous sensors. PROTECTS is currently investigating how best to apply the technology available today to enhance subway security.

Whether an attack is initially detected by chemical sensors, artificial intelligence algorithms, or through simple word of mouth from individuals at the suspect site, a methodology must be developed that will allow the OCC to confirm whether an attack is, in fact, occurring and to characterize the attack. In the event of a C/B attack, any trains in the area should be stopped by the OCC or slowed down to minimize air movement at the attack location. Since this is often considered a high consequence response, it is critical to prevent frequent false alarms. One obvious methodology to confirm attacks by fast-acting chemical agents such as nerve gas is to enable the OCC to view station platforms by video. When an attack is suspected in an area, the OCC can immediately view that area to look for the signs of an attack, and mitigating responses can be implemented if the event is confirmed. This detection methodology would prevent initiating high consequence responses when no real attack has occurred.

Consider the following scenario which could indicate a possible nerve agent release on a subway platform, similar to the attack in Tokyo. Several people run out of a station, coughing and telling the station attendant that people are collapsing down on the platform. How could the system respond to this? If an actual nerve gas attack were under way, people on the platform would indeed be affected, and it would be clear to a trained observer that a chemical release had occurred. However, in the absence of a video view of the station platform from a remote location such as the OCC, there would be no safe method to quickly investigate the situation. Since a gas cloud of this type is not visible, it would not be constructive (nor would it be safe) to require an employee to enter the area for an inspection. Anyone entering the vicinity of such an attack without proper protective equipment would likely become a casualty. Likewise, if video views of the platform were only available from within the station itself, such as a station kiosk, the employee monitoring those video screens would be at risk in the event of a gas attack. Everyone within the station should immediately be evacuated, since dangerous gases can spread throughout a station within minutes of a release. Response procedures preferably should not require employees to enter or remain within a station where an attack is suspected. Thus, having CCTV images available at the OCC would be invaluable during a suspected attack, allowing for evaluation of the situation from a safe location.

It is important to note that the detection technologies and methodologies mentioned here are still to be proven in the context of protecting subways from C/B attacks. Chemical sensors that are commercially available today have been developed for military applications, which have somewhat different sensor requirements than subway protection applications. Important issues such as sensor reliability and maintainability in the subway environment are under investigation by several agencies. Automatic pattern recognition of attack events from video or audio signals is a promising concept but requires some development. For any detection method, the potential of false alarms is an area of great concern, so combinations of multiple detection methods are under consideration for improved system reliability.

Response

Once a chemical attack has been detected in a subway, two decisions must be made immediately: how to control trains in the area and whether to turn on the emergency ventilation fans. Based on preliminary model simulations, trains running near the area of the attack should be stopped to reduce air movement and contain the C/B agent near the release location. The trains should then be moved at a crawl to the nearest safe station to allow passengers to evacuate. If a train is in a tunnel approaching the affected station, it could be reverse-railed back (if possible) to the previous station for evacuation. It is far less clear how to avoid contamination of trains that are either entering the affected station or in it. If ventilation of the trains can be controlled, then the HVAC system should certainly be shut down. Likewise, control strategies for releases that occur on-board trains are also more difficult. We have developed response guidance for the various situations that may arise and are continuing work to refine the guidance.

The control of ventilation fans after detection of a C/B attack can also involve some complex decisions. Preliminary computer simulations indicate that it would be unwise to use ventilation after the release of a very toxic biological agent. In most cases, ventilation would not significantly reduce the number of casualties within a station but would spread the contamination outside the station and thereby cause more casualties. Likewise, in the event of a large lethal chemical release in a station, ventilation might cause casualties on the street level without significantly helping those within the station. In both of these cases, containing the agent within the release location would probably be the best option. On the other hand, for a small chemical agent release, such as in the Tokyo attack, ventilation might be an attractive choice. If the release is sufficiently small, then ventilation fans might be able to dilute the gas enough to reduce casualties at the release location without risking significant contamination outside. Likewise, if an incapacitating agent such as pepper spray were released in a station, the ventilation fans might be employed to draw fresh air toward the egress routes and thereby aid a safe evacuation. Thus, optimal decisions regarding ventilation control require an evaluation of the subway system and type and quantity of released gas. On the basis of the simulations that were conducted to date, it is recommend that the more conservative containment strategy initially be employed in all cases, and that ventilation fans be turned on only after the situation has been characterized well enough to justify their use. These alternatives are now being investigated using simulation models to determine the best strategy under various scenarios.

Additional response options available on some systems today include the control of escalators and fare gates. To reduce the number of people entering a station after an attack and allow for an efficient station evacuation, station escalators should all be either switched to the outgoing travel direction or shut down. In addition, fare gates should be switched to the open position if possible to allow for rapid egress. These methods may be employed to aid station security staff in conducting a rapid and orderly evacuation.

Engineered Response [2,4]

In addition to applying the best available response options, additional engineering options such as those in Figure 4, may be applied to further mitigate attack consequences by containing and detoxifying contaminated air. Air curtains, aqueous foam, fume burners, high-temperature catalytic converters, wet scrubbers, carbon beds, and water sprays have been considered for this purpose. Initial investigations indicate that it may be possible to deploy a specialized sprinkler system with modified sprinkler heads to remove agents from the air during an attack. Standard water sprinkler systems would probably not be very effective for agent removal but instead make evacuation even more problematic. The effectiveness of even a modified sprinkler system has not yet been proven and requires further investigation.

A more effective engineered response option for protecting enclosed stations is presented by a combination of platform edge doors (PEDs), canopy hoods, and activated carbon beds. PEDs prevent air movement in the stations caused by trains and could thereby significantly reduce the spread of a released agent. In many subway systems today,

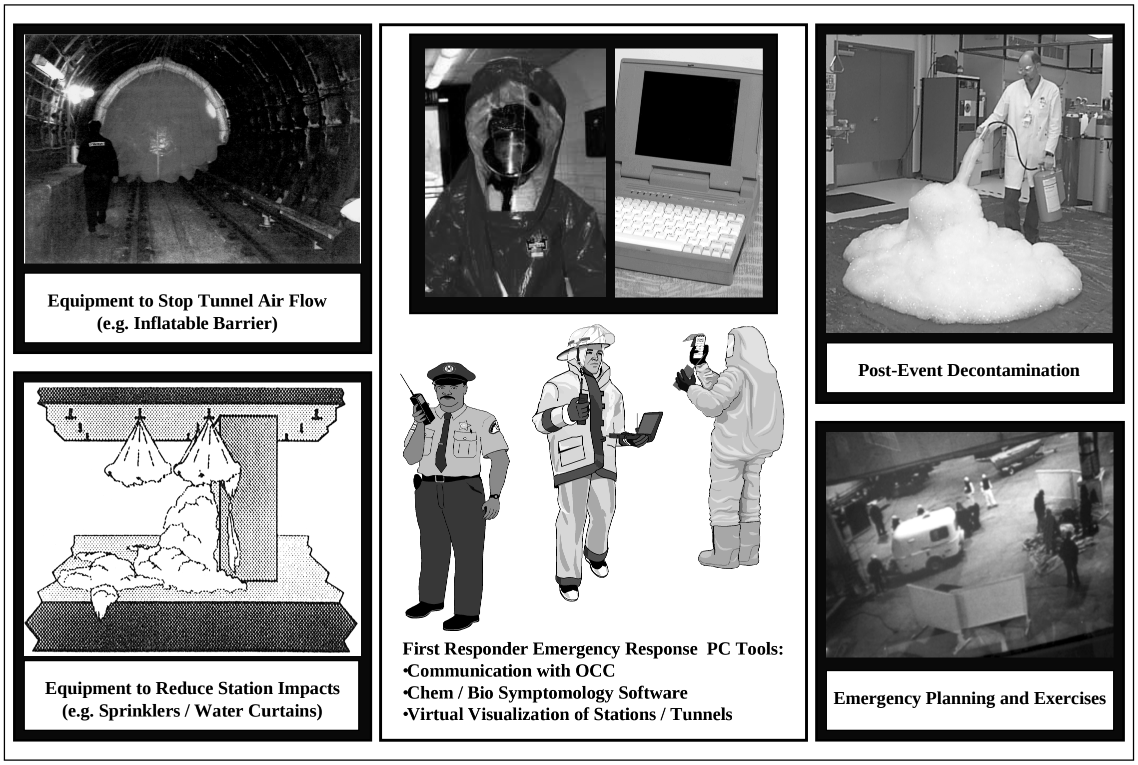

Figure 4. Sample Advanced Technology Components

ventilation is primarily achieved through train motion-induced air movement. Any C/B agent released in a station would be spread rapidly by this air movement. PEDs, which isolate the air pushed by the trains from the stations, would significantly reduce the spread of an agent. PEDs also provide safety and security benefits, preventing unauthorized access to the track area, avoiding unsafe conditions on crowded platforms, and maintaining a cleaner environment. Installing PEDs is a more appropriate solution when building new subway stations than when retrofitting older ones because of cost considerations.

To further contain an agent within a release location at train or platform level, deployable canopy hoods could be installed. They could duct the contaminated air through an exhaust manifold to a detoxification system consisting of activated carbon beds. If an attack were detected before it spread significantly through the station (which is more likely in a system equipped with PEDs), canopy hoods could be deployed above the release to prevent further agent spread and to decontaminate the area.

Maintaining fresh air in the station egress routes is also an important mitigation objective but will probably require a special engineering design for this purpose. Full station venting during a C/B attack may not be possible or desirable, as discussed above. In any case, venting from the station would not be very effective in keeping the egress route clear, given the toxicity of many C/B agents. Instead, the escape route could be enclosed and equipped with auxiliary ventilation fans, which would isolate the air from the rest of the station and allow for separate ventilation and decontamination.

Decision Support Systems

No matter what detection and response options are available in the event of a C/B attack, rapid response is required to minimize casualties. Developing response procedures and training employees often can greatly help in achieving this goal. In addition, computer-based decision support tools can be developed to help decision-makers at the OCC and the Incident Commander rapidly follow the response procedures based on the best available understanding of the situation. For example, decision support tools to aid in responding to smoke/fire events are available today. On the basis of the fire's location and train locations, and by using tabulated results generated from simulated fires, computer calculations can lead to recommended optimal ventilation control strategies. These strategies can be implemented with a single confirmation by an OCC operator. This method clearly improves the response time over that of a manual system in which the operator must choose and implement a ventilation strategy "on the fly." Similar decision support tools will be developed for response to C/B attacks using whatever resources and information are available more quickly and efficiently. The OCC and Incident Commander would share the same information on their separate computers. Figures 3 and 4 illustrates technology tools being developed by PROTECTS for coordinated system-wide chemical agent emergency response.

CONCLUSIONS

The preparation of subway systems to deal with terrorist chemical or biological agent attacks is an important and difficult problem. Early warning, rapid response, and engineered mitigation methods can save many lives in such an incident. A well-prepared system can significantly reduce the impacts of an attack and may discourage such attacks from taking place. The U.S. Department of Energy PROTECTS program is working with subway systems to develop and implement technological solutions for improved preplanning and for more effective responses to such terrorist incidents.

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